NOTES ON MIMETITE, THAUMASITE, AND WAVELLITE.

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The following brief papers are the results of studies made in the mineral collections of the United States National Museum.

MIMETITE FROM UTAH.

A specimen labeled "Penfieldite, Tintic District, Utah," in a United States Geological Survey collection, transmitted to the museum in 1902 (No. 85013), was examined by Mr. E. S. Larsen in the course of his optical study of all available minerals and found to be quite distinct from penfieldite in its optical properties.[2] It has therefore been further investigated, and proves to be mimetite in a rather unusual form—transparent, colorless, acicular crystals. Crystals from what is evidently the same occurrence have been described and figured by Farrington and Tillotson,[3] but very few forms were observed upon them. The crystals on the United States National Museum specimen being rich in forms, this account of them has seemed desirable.

The specimen is a 5 by 5 by 8 cm. mass of siliceous rock, containing numerous small cavities lined with drusy quartz, and on one face several imbedded galena crystals in an advanced state of alteration. The mimetite crystals occur in the cavities, being especially abundant on the galena-bearing side, and are subsequent to both galena and quartz.

The thinner crystals are colorless and transparent, with an adamantine luster; thicker ones have a faint yellowish hue and are more resinous. The mean index of refraction of one of the needles, measured on the goniometer by allowing sodium light to be refracted through faces lying 30° apart, proved to be 2.14 ± 0.02. Mr. Larsen found by the immersion method in selenium-sulfur mixtures $\omega = 2.14$, $\varepsilon = 2.13$, both ± 0.02, agreeing essentially with the results given in the literature for mimetite.

[1] This paper was prepared while the writer held the position of Assistant Curator of the Division of Mineralogy and Petrology in the United States National Museum.

[2] American Mineralogist, vol. 2, 1917, p. 20.

[3] Field Columb. Mus. Publ. 129, Geol. Ser., vol. 3, No. 7, 1908, p. 150, pl. 50.

Two habits are represented among the crystals. The most abundant habit, shown in idealized diagram in figure 2, is acicular, the crystals averaging 0.1 mm. in diameter and 5 mm. in length. Two prisms are well developed, the second-order one being usually dominant, both showing slight curvature and vertical striation. These needles are mostly terminated simply by a basal plane, but occasionally pyramid faces are present. The other habit, represented by a very few crystals, is similar to that figured by Dana for the mineral, a single stout prism terminated by pyramids of the same order, the prism being horizontally striated like quartz, as shown in figure 1. It might be supposed that two different minerals are represented, but the angles of both types proved to be identical.[1]

As the average of a number of good measurements the ρ angle of the principal pyramid was found to be 40° 02′, the value adopted by Professor Goldschmidt in his "Winkeltabellen"; the figure of Haidinger (39° 50′), cited by Dana, being undoubtedly in error. This makes the axial ratio $c=0.7275$ in the orientation usually adopted for hexagonal minerals in this country (G_2), equivalent to $c=1.260$ in Professor Goldschmidt's (G_1) position. The angles of the other forms shown in the figures correspond to this ratio. Not only are all of the forms heretofore reported on this mineral present, but two new forms, which are named α (symbol $30\bar{3}2$) and z ($30\bar{3}1$) are also developed, the first on a crystal of the acicular habit, the other on a prismatic one:

ρ_α calculated, 51° 34′, observed 51° 20′±20′.
ρ_z calculated, 68° 45′, observed 69° 00′±20′.

It was thought best to confirm the optical and crystallographic identification of the mineral as mimetite by chemical tests. Removal of sufficient material for a complete and accurate analysis would have destroyed the specimen, but 0.0060 gram of acicular crystals were picked out of inconspicuous cavities and analyzed as fully as possible. The mineral is readily soluble in cold dilute nitric acid, and from such a solution the chlorine was precipitated by silver nitrate, and after removal of excess silver and evaporation the lead was precipitated by hydrochloric acid and alcohol, the precipitates being collected and weighed on a small Gooch crucible. Part of the arsenic was volatilized by the evaporation, but hydrogen sulfide precipitated the remainder, and after removal of the excess of the reagent and evaporation with nitric acid ammonium molybdate failed to yield a precipitate, showing the absence of phosphorus.

[1] The United States National Museum equipment not including a Goldschmidt two-circle goniometer, all measurements of crystal angles described in this paper have been made on the one in the Geophysical Laboratory of the Carnegie Institution, and thanks are herewith extended to Messrs. Wright and Merwin, of that laboratory, for their kindness in placing this instrument at the writer's disposal.

The results obtained were: Lead oxide 73.3, chlorine 2.5, arsenic pentoxide by difference 24.7 per cent, agreeing closely with the theory for mimetite.

This constitutes a good example of the value of optical study of rare or unsual minerals. Had Mr. Larsen not examined this specimen and discovered that its optical properties differed from those of penfieldite, it would in all probability have continued indefinitely to be treasured as a specimen of that rare mineral, which it certainly resembles in superficial aspect more than it does mimetite.

THAUMASITE.

CRYSTALLOGRAPHIC MEASUREMENTS OF THAUMASITE.

The first thaumasite discovered, from several localities in Sweden, was massive, but proved to be optically uniaxial, showing it to belong either to the tetragonal or hexagonal crystal system, and it is so classed by Dana.[1]

The material subsequently found at West Paterson, New Jersey, was described by Penfield and Pratt as forming a loose aggregate of hexagonal prismatic crystals.[2] A terminated crystal has been recently measured by Dr. W. T. Schaller;[3] it shows the base, 0001, a pyramid p, taken as the unit, $10\bar{1}1$, and a prism, m, of the same order as the pyramid, the symbol of which is accordingly $10\bar{1}1$. The angle ρ between the pyramid and the base averaged 51° 30′, whence Doctor Schaller calculated the axial ratio of the mineral to be $c=1.09$.

Early in 1916 Mr. James G. Manchester, president of the New York Mineralogical Club, sent the United States National Museum a number of minerals from New York and New Jersey in exchange, and among the lot was 25 grams of crystallized thaumasite, representing about 50,000 tiny crystals, mostly less than 1 mm. in length.

The vast majority of the crystals, though doubly terminated, show but two forms, the first order prism and the base, but three hours' search under a binocular microscope disclosed five crystals showing several distinct pyramidal faces and a few faces of the second order prism. These were submitted to crystallographic measurement, and a preliminary announcement of the results was made in August, 1917.[4]

Shortly after the appearance of this preliminary announcement there was received in this country from Stockholm, Sweden, the April, 1917, number of the Geologiska Föreningens Förhandlingar, in which Dr. Gust. Flink announced the discovery of measurable crystals of

[1] System of Mineralogy, ed. 6, 1892, p. 698.

[2] On the occurrence of thaumasite at West Paterson, N. J. Amer. Jour. Sci., ser. 4, vol. 1, 1896, p. 229.

[3] The crystallography of thaumasite; in Mineralogical notes, Series 3; Bull. U. S. Geol. Surv. 610, 1916, p. 130.

[4] Amer. Mineralogist, vol. 2, 1917, p. 89.

thaumasite at Longbanshyttan.[1] A supplementary note calling attention to this was then published in the American Mineralogist.[2]

The crystals described by Doctor Flink are remarkably like those from West Paterson; they agree in size, habit, frequency of double termination by base, rarity of pyramid faces, dullness of base, etchings on prism faces, etc. He found two crystals with measurable pyramid faces, on one of which two angles, from pyramid to prism, proved to be 42° 24′ and 42° 26′; the corresponding angle with the base (ρ) is 47° 35′, whence the axial ratio c=0.9479. No other forms were observed.

Some uncertainty would naturally be attached to a ratio based on two measurements on a single crystal which was admittedly rather poorly developed. When compared with the results obtained by the writer on the New Jersey crystals, which are given in full below, it will be seen that the difference between the two sets of measurements is but 30′, and the corresponding difference in axial ratio 0.017; but since the writer's value is based on 26 measurements, on four forms, on five different crystals, it is believed to be nearer the true axial ratio for the species.

The crystals measured are from 0.5 to 1.5 mm. long and 0.3 to 0.7 mm. in diameter. The basal planes are dull, and yield only faint reflections; the pyramid faces are none too brilliant, and are mostly somewhat curved, so that they distort the image of the signal a little; the prism faces are the best of all, yielding brilliant images, although the existence of intergrowth with subparallel crystals makes itself evident in frequent multiplicity of images. None of the terminations is perfect, only from one to four of the possible six pyramid faces being developed; nor were any of the crystals found to be doubly terminated with pyramids; in every case the opposite end to that showing pyramid faces is terminated by the base alone. This suggests that the mineral is hemimorphic, but this could not be confirmed by etch-figures, since etching with dilute acids and with water containing carbon dioxid yielded nothing but narrow grooves without definite crystallographic features. The rather poor quality of the faces renders the measurements somewhat unsatisfactory, but the axial ratio of the mineral can certainly be regarded as established and the presence of several new forms proved.

One pyramid appears on all five crystals, yielding fairly good reflections in several instances, and its ρ was found to average 47° 5′±15′. This is evidently the same form observed by Doctor Schaller, the discrepancy in angles being due to the fact that he was unable to obtain definite signals with his crystal, and so was obliged to locate the pyramid by maximum illumination, a method incapable of yield-

[1] Geol. För. Förh., vol. 39, 1917, pp. 447–452.
[2] Vol. 2, 1917, p. 125.

ing accurate results. This pyramid is taken as the unit 101, and yields the axial ratio for thaumasite:

$$c=0.931\pm0.003.^{1}$$

Three other pyramids and the second order prism were also observed, making the total number of forms now known on the mineral 7. The results of the measurements of the angles of these forms, contrasted with the theoretical values, are given below, and an idealized combination of all the forms in figure 3. The zone of pyramids represents Professor Goldschmidt's harmonic series N_3, three members being absent:

	Form:	0001	....	$10\bar{1}2$	$20\bar{2}3$	$10\bar{1}1$	$30\bar{3}2$	....	....	$10\bar{1}0$
Observed:	p :	0	....	1	2	1	3	....	....	inf.
	q			–	–		–			
				2	3		2			
				1	1	2	3			
Theory:	N_3 :	0		–	–	–	–	3	2	inf.
				3	2	3	2			

The combination of forms on the separate crystals are:

Crystal No.	Forms.
1	c, a, m, e, p
2	c, m, p, q
3	c, m, p, q
4	c, m, p, q
5	c, a, m, f, p, q
Majority	c, m

Measured and calculated angles of thaumasite.

[New forms marked *.]

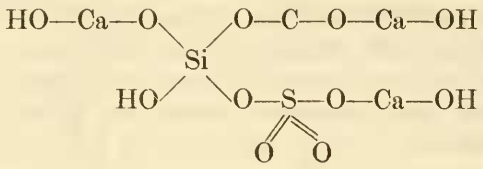
No.	Letter.	Symbol.	Number of crystals.	Number of measurements.	Measured.					Calculated.			
					ϕ		ρ		$\pm$	ϕ		ρ	
					°	′	°	′	′	°	′	°	′
1	c	0001	5	1	..	..	0	10	30	..	..	0	00
2	a*	$11\bar{2}0$	2	2	30	05	90	05	30	30	00	90	00
3	m	$10\bar{1}0$	5	28	0	00	90	00	60	0	00	90	00
4	e*	$10\bar{1}2$	1	4	0	00	30	00	120	0	00	28	16
5	f*	$20\bar{2}3$	1	2	0	00	38	00	120	0	00	35	38
6	p	$10\bar{1}1$	5	10	0	00	47	05	15	0	00	[47	05]
7	q*	$30\bar{3}2$	4	10	0	00	58	00	30	0	00	58	12

THE CHEMICAL CONSTITUTION OF THAUMASITE.

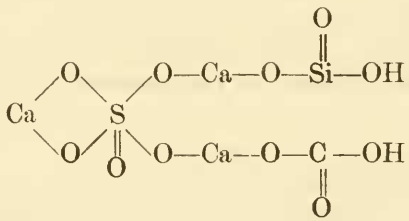
Thaumasite is one of the few minerals containing three different acid radicals, carbonate (CO_3), silicate (SiO_3), and sulfate (SO_4), as essential constituents; is it to be classed as a carbonate, a silicate,

[1] Axial ratios are often calculated to the fourth, fifth, or sixth decimal place, but when there is a variation of 3 units in the third place such extensions are without significance.

or a sulfate? Dana[1] placed it in a "concluding division" of silicates. Penfield and Pratt[2] not only accepted its interpretation as a silicate, but even wrote the following constitutional formula with silicon as linking element:



Now that it has been discovered that sulfates played an important rôle in the zeolite deposits of the Watchung Mountain region, which yield far more thaumasite than all other localities put together, the view suggests itself that this mineral is a sulfate, a derivative of anhydrite, as expressed in the structural formula below:



This formula agrees with the following facts:

1. Thaumasite is derived, in the Watchung Mountain region, by the action on anhydrite ($CaSO_4$), (or on the calcium sulfate portion of glauberite ($CaSO_4+Na_2SO_4$)), of solutions capable of depositing calcium carbonate (calcite) and silicates (zeolites).

2. It contains 15 molecules of water, but, as has been shown by Dr. H. E. Merwin,[3] 14 of these go off as the temperature is increased without a break in the dehydration curve, and must be regarded as "water of crystallization;" the last one is driven off only at red heat. The formula given shows that two hydroxyl (OH) groups are present, joined to different elements, which accounts for the high temperature needed to cause them to unite and liberate water (H_2O).

It is, of course, not to be inferred that in the crystalline mineral the atoms are actually arranged in the manner indicated, for from recent work in crystallography, especially the application of X-rays to the study of crystal structure, it is known that the atomic arrangement in crystals is based on geometrical rather than chemical relationships. Such a structural formula means, therefore, merely that

[1] System of Mineralogy, ed. 6, 1892, p. 698.
[2] Amer. Journ. Sci., ser. 4, vol. 1, 1896, p. 229.
[3] Journ. Wash. Acad. Sci., vol. 4, 1914, p. 496.

development of molecules of this structure in solutions led to the crystallization of the mineral in the first place.

Thaumasite is, accordingly, regarded as a sulfate, and it is recommended that it be described chemically as "di-hydroxy-tricalcium carbono-silico-sulfate, crystallizing with 14 molecules of water in the hexagonal system." It probably belongs in the same group as connellite and hanksite, which are similar in crystallization.

CRYSTALLOGRAPHIC MEASUREMENTS ON WAVELLITE FROM HELLERTOWN, PENNSYLVANIA.

In an abandoned iron mine 1 mile southeast of Hellertown, Northampton County, Pennsylvania, the locality of the beraunite described in an earlier paper in this series,[1] wavellite has long been known to occur, and in 1910 the writer found two specimens containing measurable crystals, which are rarely met with in this mineral.

The wavellite is in acicular crystals in divergent groups in cavities in ferruginous sandstone. These are very minute, rarely exceeding 0.1 mm. in diameter, but their faces are brilliant and yield fairly good reflections, although subparallel intergrowth renders the angles somewhat variable. The indices of refraction, measured by the immersion method, are $\alpha=1.525$, $\beta=1.535$, and $\gamma=1.550$, all ± 0.005; the specific gravity is 2.325. The results of the crystallographic measurements are tabulated below. The form p, (121), is best developed, and gives reflections which can be read accurately to about 5^1; but the results vary 30′ or more from one crystal to another, so that the axial ratio can not be determined beyond the third decimal place. The average angles for this form proved to be: $\varphi=41°\ 45'$; $\rho=47°\ 15'$, whence the ratios are: $a:b:c:=0.564:1:0.404$. In all 8 certain and several doubtful forms are present; one of their modes of combination is shown in figure 4; other crystals are like those figured by Dana.

The forms are:

b (010) well developed.
a (100) traces, in the midst of striations of prism zone.
l (430) traces, in the midst of striations of prism zone.
m (110) well developed.
n (340) traces, in striations.
p (101) prominently developed, but dull.
s (111) minute, though fairly bright.
o (121) fairly well developed, brilliant.

All the material which could be spared without destroying the specimens, amounting to 0.4 gram, was submitted to the firm of

[1] Proc. U. S. Nat. Mus., vol. 47, 1914, p. 507.

Booth, Garrett & Blair, of Philadelphia, for analysis, and the results, obtained by Mr. Frederick Wynkoop, of that firm, were:

Analysis of Wavellite from Hellertown, Pennsylvania.

	1	2	3
Al_2O_3	36.5	0.358	3.03
P_2O_5	33.4	0.236	2.00
F	0.8	0.040	13+
H_2O	28.6	1.580	
SiO_2	1.1	.....	.....
Total (less O=F 0.3)	100.1	.....	.....

1. Results of analysis; the fluorine figure is known to be too low, but the material available was insufficient for its accurate determination. 2 and 3, ratios.

This agrees exactly with the Groth formula for the mineral, $(Al(OH,F))_3(PO_4)_2+5H_2O$, which differs from that adopted by Dana in allowing for the fluorine and in recognizing the presence of an additional half molecule of water. Written in expanded form, this is $3Al_2O_3.2P_2O_5.13(H_2O, 2HF)$.

THE AXIAL RATIO OF WAVELLITE.

A number of occurrences of wavellite have been studied crystallographically, but the axial ratios obtained exhibit slight variation, as brought out in the following table, in which the determinations are arranged in chronological order:

Date.	Authors.	Source.	Axis *a*.	Axis *c*.	φ_m	$m\Lambda m'''$
					° ′	° ′
1830	Senff (adopted by Dana and Goldschmidt).	.....	0.5049	0.3751	63 13	53 35
1897	Cesaro	Belgium	0.5573	0.4084	60 52	58 16
1912	Ungemach	Pennsylvania[1]	0.5577	0.4057	60 51	58 18
1912	....do	Montebras	0.5577	0.4057	60 51	58 18
1917	E. T. Wherry	Hellertown, Pa	0.5640	0.4040	60 35	58 50
Average (excluding Senff's)			0.559	0.405	60 47	58 25

[1] The locality was stated as "Cly, York Co., Pa.," but this is merely the site of the factory where the wavellite was used as a source of phosphorus; the mineral really came from Mount Holly Springs, Cumberland County.

This variation is undoubtedly due to the fact that the majority of the crystals measured have been very minute and imperfectly developed, subparallel intergrowth in particular being almost invariably present. There seems no good reason to assume that we know the axial ratio of wavellite with greater certainty than ± 0.005, so the values should be stated only to the third decimal place; but the average values given are probably very close to those actually characteristic of the mineral.

EXPLANATION OF PLATE 56.

The figures are somewhat idealized diagrams of the crystals described. New forms are marked with an asterisk * below.

FIG. 1.—Mimetite, Tintic District, Utah; Prismatic habit; a combination of c (0001), a ($10\bar{1}0$), x ($10\bar{1}1$), y ($20\bar{2}1$), z* ($30\bar{3}1$), and π ($40\bar{4}1$).

2.—Mimetite, same locality; acicular habit; c (0001), a ($10\bar{1}0$), b ($11\bar{2}0$), h ($21\bar{3}0$), x ($10\bar{1}1$), α* ($30\bar{3}2$), y ($20\bar{2}1$), s ($11\bar{2}1$), and m ($21\bar{3}1$).

3.—Thaumasite, West Paterson, New Jersey, showing all the forms observed; c (0001), a* ($11\bar{2}0$), m ($10\bar{1}0$), e* ($10\bar{1}2$), f* ($20\bar{2}3$), p ($10\bar{1}1$), and q* ($30\bar{3}2$).

4.—Wavellite, Hellertown, Pennsylvania; a combination of b (010), a (100), l (430), m (110), n (340), and o (121).